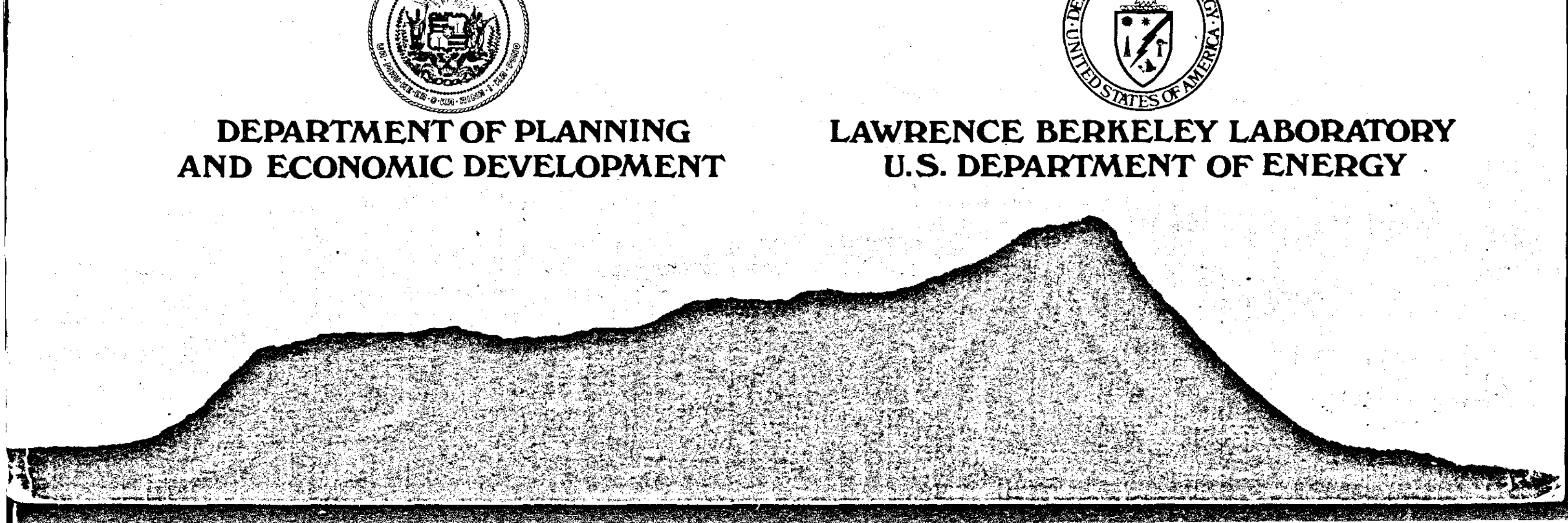
HAWAII INTEGRATED ENERGY ASSESSMENT

EXECUTIVE SUMMARY

DEPARTMENT OF PLANNING
AND ECONOMIC DEVELOPMENT

LAWRENCE BERKELEY LABORATORY
U.S. DEPARTMENT OF ENERGY



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Lawrence Berkeley Laboratory
University of California
Berkeley, California

State of Hawaii
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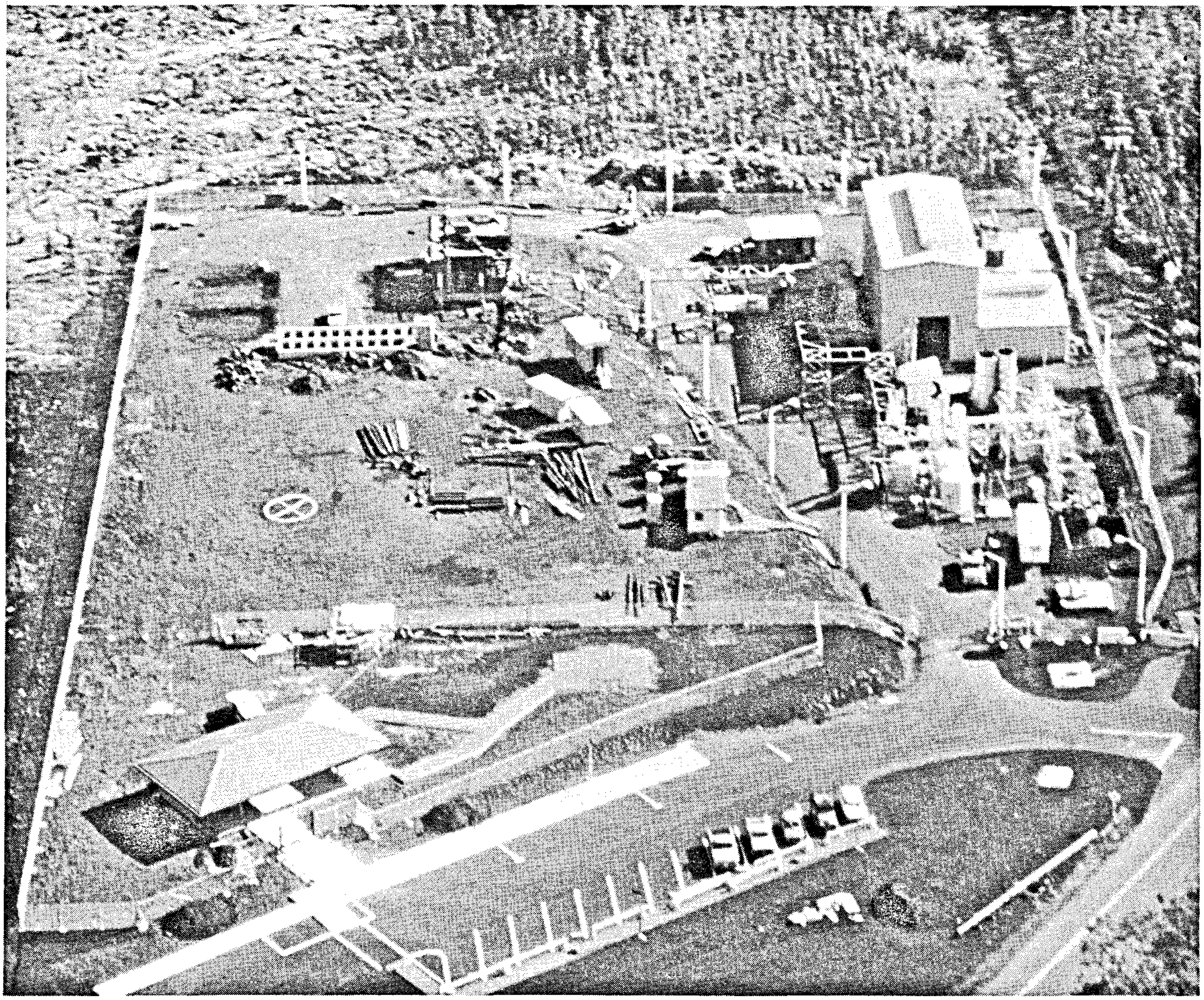
Contents



Construction of the geothermal power plant in the Puna District of the Big Island of Hawaii was to be completed early in 1981.

Preface

The Hawaii Integrated Energy Assessment (HIEA) is designed to aid decision-makers in Hawaii as they plan the transition from nearly total dependence upon oil to a mix of renewable, indigenous energy resources during the next 25 years. Recognition that an integrated assessment of Hawaii's energy future would be useful during this transition grew out of discussions between the State of Hawaii Department of Planning and Economic Development (DPED) and the San Francisco Operations Office of the United States Department of Energy (DOE). Subsequently commissioned by DOE with funding from its Office of Solar Strategy, Analysis and Integration, and the Office of Resource Applications, with further assistance from the State of Hawaii, this study was undertaken as a collaborative effort by the Lawrence Berkeley Laboratory and DPED.

This assessment is intended to be as realistic as possible in its analysis of the prospects for commercial evolution of the energy technologies that are appropriate for Hawaii and in its examination of the many-faceted implications of developing those technologies. As a result, the HIEA conclusions may be more restrained than those with a more optimistic range of opinions might expect.

This report offers a series of views of possible future events. Like any other look into the future, it becomes more tenuous the farther it reaches. It is not intended as a definitive evaluation of the alternate energy technologies it considers nor as a precise forecast of things to come. The basic analytical models used in the assessment, however, will continue to be useful tools if updated data are introduced over the years. The transition to indigenous energy resources will call for a sequence of aggressive, informed decisions as the real future unfolds. It is hoped that the information presented in the seven volumes of the HIEA report will provide a sound basis for these decisions.

The many experts from diverse fields and institutions who participated in these studies are acknowledged in the appropriate volumes. We commemorate here the late Dr. Eugene M. Grabbe, former Manager of the DPED's State Center for Science Policy and Technology Assessment, for his key role in initiating the project and guiding its earliest work.

Bagasse is sugarcane waste – the residue after sugarcane stalks have the sugar removed. It is produced by the thousands of tons in Hawaii and is excellent fuel for power plants generating electricity. Other forms of biomass also can be used to help Hawaii replace petroleum and become more self-sufficient in energy.

Introduction

Hawaii's generous endowment of indigenous, renewable energy resources could deliver the state from its all but complete dependence on imported petroleum. With 92% of its energy derived from imported oil — and 64% of that from foreign sources — Hawaii is highly vulnerable to the full impacts of rising oil prices and the growing risk of supply disruptions. This study addresses the questions of how, when and to what extent Hawaii's abundant geothermal, wind, solar, ocean thermal and biomass energy resources can be harnessed to displace oil during the next 25 years.

In part, the answers are cast in the form of feasible "energy futures" for the evolution of these indigenous resources in each of the counties. The projections of the means by which Hawaii's future energy demands can be met are based on evaluations of technologies considered appropriate to Hawaii, estimates of their future costs, and directly relevant economic parameters projected by the state. Environmental impacts, institutional structures, the relevant body of laws and regulations, and social attitudes that may constrain resource development were also taken into account.

Three energy demand-supply projections were structured to quantify the transition to the commercial use of indigenous resources. Energy Futures 1 and 2 take form partly in response to an average 3% per year increase, over inflation, in the price of oil. Future 2, however, incorporates improvements in end-use energy efficiency and conservation beyond those induced by oil price alone. Future 3 is shaped by a high rate of increase in world oil price — 10% per year over inflation. While a sustained price escalation at this rate would be severely disruptive to society as a whole, it serves the purpose here of providing perspective on the sensitivity of a transition to indigenous resources attributable to oil price alone.

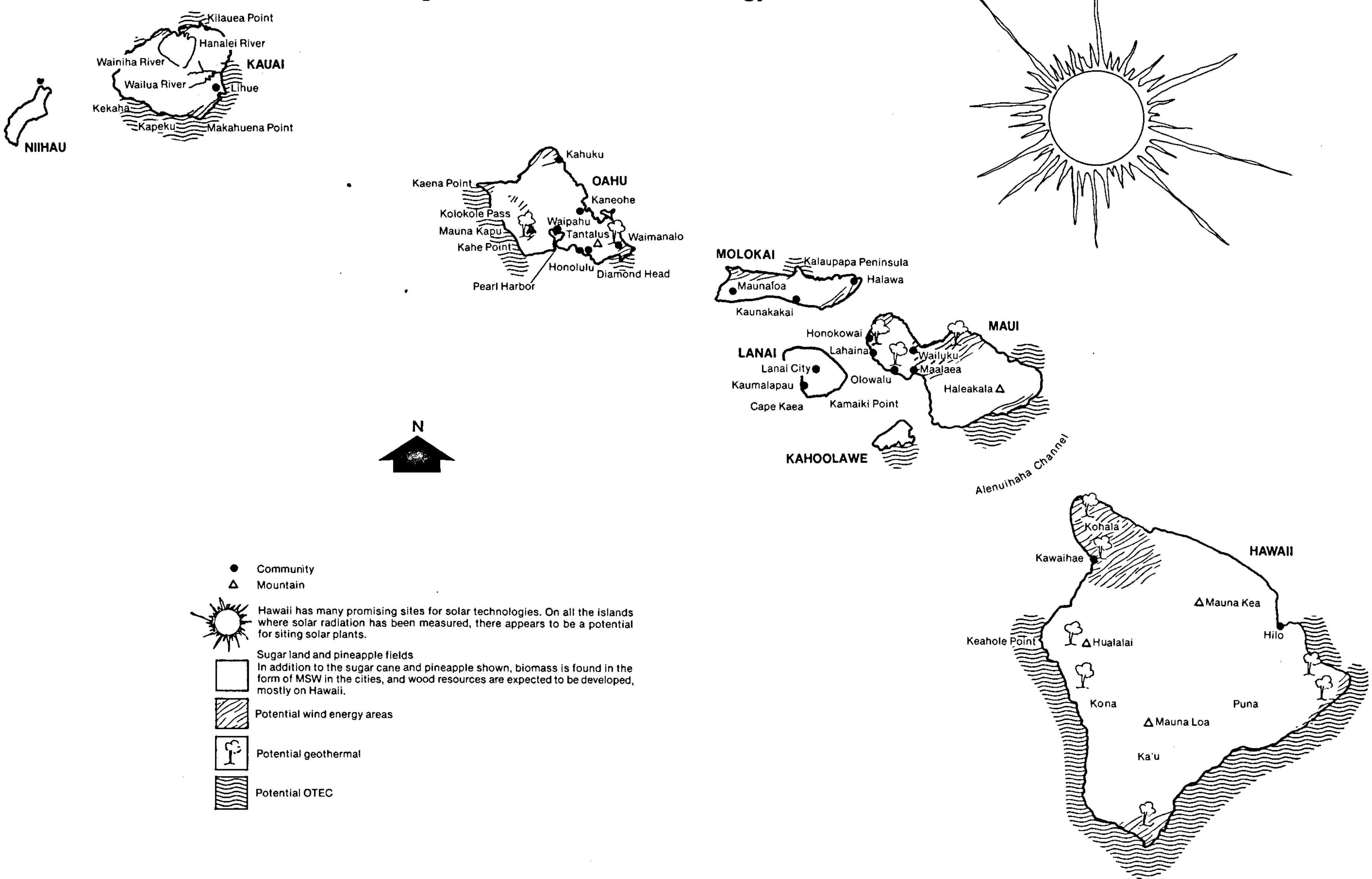
The analysis embraces only the civilian use of energy and does not take into account U.S. Department of Defense activities. It also excludes petroleum products refined in and exported from Hawaii. Commercial aviation, the largest consumer of petroleum products, is dealt with separately from the other demands for energy. There is no foreseeable indigenous source of jet fuel (hydrogen-fueled aircraft are not expected within the time frame of this study, if at all) and consequently, aviation fuel use would affect the transition from oil to indigenous resources only indirectly through the general economy. This linkage is taken into account but its full ramifications are not explored.

By providing an approach to integrated energy analysis for Hawaii, this assessment offers a model for decision-makers in a region, state or small country who must plan to meet the need for energy in a time of growing shortfalls and rising oil prices. This report is intended to help Hawaii plan conversion to the resources it has without relying entirely on one technology or one source of energy. Only after all the feasible options have been examined can a reasonable emphasis be placed on those most likely to meet the state's energy needs. Future events will certainly alter specific details, but the method of analysis used in this study is highly adaptable and should give decision-makers a basis for flexible response to changing circumstances.

The report of the study is presented in six numbered volumes and this Executive Summary. Volume I both summarizes and integrates the findings of the study to present a composite picture of how Hawaii's energy future could evolve. Volume II, *Alternate Energy Technologies for Hawaii,* and Volume III, *Projecting Hawaii's Energy Future: Methodology and Results,* evaluate the energy technologies and describe the analytical methodology employed in this study. Volume IV, *Energy Data Handbook,* provides baseline series of energy and related data essential for the development of alternate energy planning.

Volume V, *Rules, Regulations, Permits and Policies Affecting the Development of Alternate Energy Sources in Hawaii,* provides a comprehensive review of required permitting procedures, indexed by type of permit and technology. This volume, which is expected to be of great practical use to those interested in implementing alternate energy technologies, also outlines the major federal, state, county and other institutional regulations and policies affecting energy development in Hawaii. Volume VI, *Perceptions, Barriers and Strategies Pertaining to the Development of Alternate Energy Sources in the State of Hawaii,* focuses on the views expressed in a survey of a wide cross section of Hawaii residents concerning priorities in energy development, conservation, the environment, and the economy. It outlines the major social constraints perceived and suggests strategies for mitigating those constraints. A brief discussion of the major conclusions of Volume VI can be found in Volume I.

Figure 1. Hawaii's alternate energy resources.



Summary of Major Conclusions

1. *Electricity.* By the year 2005, Hawaii could produce as much as 90% of its electricity with indigenous, renewable resources. Economic analysis shows that these resources could compete favorably in Hawaii under a wide range of oil prices and levels of energy conservation and that the rate at which indigenous resources can be exploited depends more on the rate of technological development and the availability of capital than on oil price. If oil prices continue to rise, the use of renewable resources for electricity generation would help stabilize electricity prices.

2. *Liquid Fuels.* The prospects are less bright for liquid fuels, which represent about 60% of all the energy used in Hawaii. This is largely because there is no indigenous substitute for the jet fuel which represents 32% of Hawaii's energy use and which is central to Hawaii's economy. At least 10% of the gasoline consumed could be replaced by liquid fuels produced from biomass, making it possible for all vehicles in the state to run on a 10% alcohol/90% gasoline mixture. Little liquid fuel should be needed to generate electricity by 2005.

3. *Undersea Cable.* A submarine transmission cable is critical to Hawaii's energy future. Geothermal energy is the only large-scale, indigenous, baseload electricity source that is now commercially mature. The only proven geothermal resources in the state are on the Island of Hawaii. The resource is unlikely to be fully developed unless the electricity it produces can be exported to Oahu, which consumes 82% of the state's electricity.

4. *Economic Impacts.* Replacing imported petroleum with indigenous energy sources would have a beneficial effect on Hawaii's economy. Over the next 25 years, the use of renewables could save the state between $7 and $22 billion, depending on the price of oil. Constructing new energy facilities would not have a major economic impact on the state, but Hawaii's utility companies would encounter financing difficulties during the peak construction period unless present financing rules and practices were modified.

5. *Conservation.* Energy conservation could lead to substantial reductions in electricity and gasoline consumption. Improved appliance and building efficiencies and the use of heat pumps and solar water heaters could cut electricity use by 25%. The federally-mandated automobile mileage standard is expected to reduce gasoline consumption by 60%.

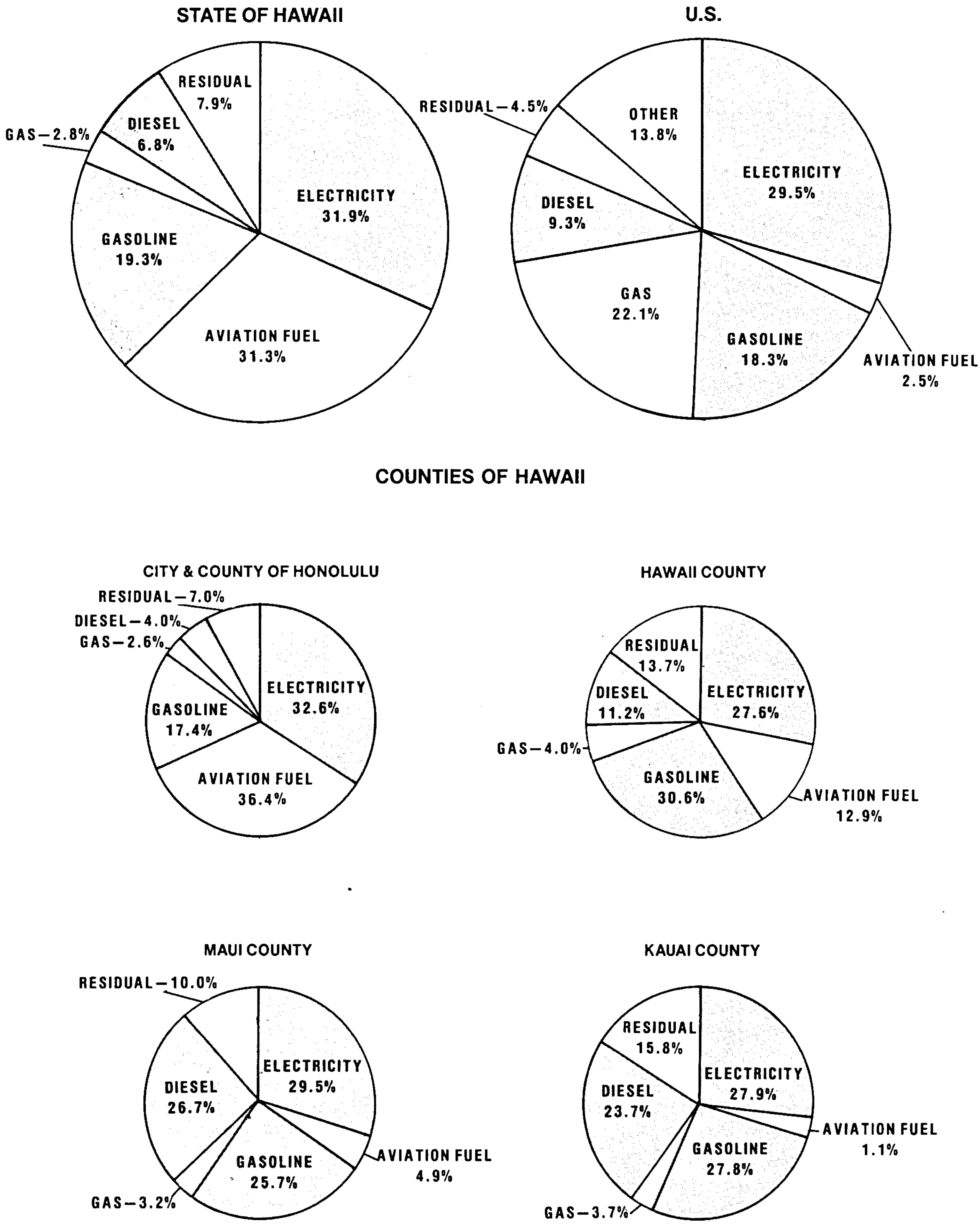
6. *Coal.* If the undersea cable and OTEC are long delayed or prove impractical, coal could substitute for oil or for indigenous resources. If plans to use domestic coal were made immediately, Hawaii could be released from its dependence on imported foreign oil sooner than it would if the state waited for renewables to reach maturity. The use of coal would pose environmental problems, particularly with air pollution and solid waste disposal.

7. *Public Opinion.* A large majority of Hawaii residents consider energy as serious a social issue as crime, inflation or unemployment, and public awareness of new energy technologies is high. Consumers know less about energy end uses and will not necessarily place energy savings above convenience in purchasing new cars and appliances. Increasing energy costs seem to affect energy use patterns more than a desire to conserve. State strategies for increased public support of self-sufficiency programs include strengthening public information programs, providing accurate and timely information on proposed projects, and making energy use data more readily available to consumers.

About Inflation . . .

Throughout this report, costs and prices are expressed in 1980 dollars unless otherwise stated. That means that price increases shown are in addition to inflation. Energy values are given in British thermal units (Btu). In the case of electricity, the term "energy value" means the primary energy input needed to generate and deliver the electricity, assuming a heat value of 11,150 Btu/KWh (kilowatt hour). Capacity, or electric power, however, is expressed as electricity output in megawatts (MW). Energy equivalents in millions of barrels of oil (Mbbl) are approximated by a heat value of 5.8 million Btu/bbl, although it must be borne in mind that petroleum products vary in heat value, and more than one barrel of crude oil is needed to make one barrel of refined product.

Figure 2. Energy consumption by energy type, Hawaii and the United States: 1977



Hawaii Today

Hawaii's 965,000 residents (over 1.1 million if visitors are included) are distributed among several islands separated by ocean channels ranging from seven to 72 miles in width and from 108 to 10,000 feet in depth. Hawaii's four counties have separate electricity supply systems, and they have different resources for producing electricity. Geothermal resources, for example, are most likely to be developed on the Big Island, whereas promising wind sites are found on every island, and hydropower is most developed on Kauai and Hawaii. The counties also differ in their anticipated economic and demographic growth patterns. The state has no fossil fuel resources of its own.

The total 1979 civilian energy consumption in Hawaii is estimated to have been 211 trillion Btu, which is equivalent to about 37 million barrels of oil. The energy equivalent of 3 million barrels was supplied by burning bagasse (7% of state energy supply) and other agricultural wastes, and by 15 hydroelectric plants (1%), so Hawaii needed to import 34 million barrels of oil at a cost of nearly $1 billion to meet its energy needs in 1979.

Because approximately 80% of the state's population, businesses, government offices and other facilities are located in the City and County of Honolulu, it is not surprising that Honolulu accounted for 82% of the state's total energy consumption. Hawaii County consumed about 7.5%; Maui County about 7.2%; and Kauai County, 3.3%. (See Figure 3.)

Energy supply and demand systems are complex and do not lend themselves readily to prompt, precise reporting. For the present purpose, however, the most recent, highly detailed data available, which are for 1977, are adequate to characterize recent energy demand trends in Hawaii.

Figure 2 shows the relative proportions of major liquid fuels and electricity consumption in Hawaii by county, state and, for comparison, the nation in 1977. It is evident that an important feature of Hawaii's energy picture is the large proportion of energy used for transportation and the large fraction of that use which goes to aviation fuel. The energy used in the form of electricity is particularly significant for Hawaii because electricity generation possesses the greatest potential for a major shift from oil to indigenous resources. Electricity represents 32% of the state's total energy use, but it accounts for only 25% of the total demand for oil. Hawaii uses less electricity per capita than the country as a whole because it has relatively little heavy industry and almost no space heating.

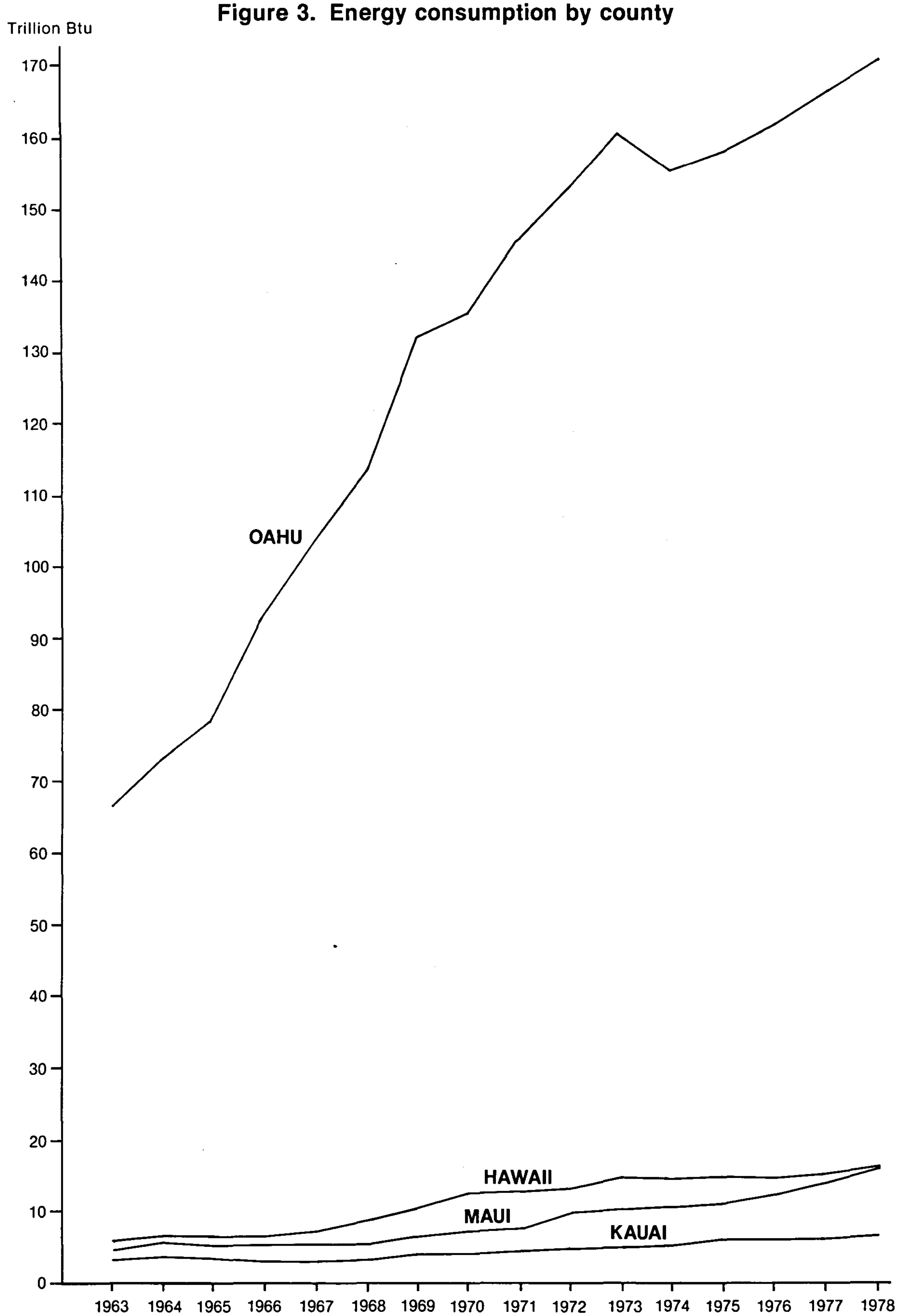
Since the 1973-74 oil embargo, Hawaii's civilian energy consumption has slowed to an annual increase of 2.5%, compared to the 5% per year growth rate that prevailed in the preceding five years and the still higher growth rate in the 1960s. The slower growth is largely attributable to changes in aviation fuel use. Between 1963 and 1970, it increased nearly four-fold but then began to level off with the introduction of wide-bodied aircraft. After 1973, jet fuel consumption tended to remain within a small range around 63 trillion Btu per year (11 million barrels/year). The estimated 35,000 barrels a day of aviation fuel used in 1980 represented nearly one-third of the state's total energy demand. The future demand for aviation fuel, based on projections of growth in tourism, population and the economy, is expected to reach 58,000 barrels per day by 2005, an increase of 66%. Aviation is crucial to tourism, the state's primary industry. Each year since 1975 Hawaii has asked Congress to establish a strategic petroleum reserve in Hawaii which could act as an emergency supply in case of severe disruptions in imports. So far this program has not been funded.

The demand for diesel fuel, residual oil and gas has been fairly stable since 1973. In contrast, sales of electricity and gasoline continued to grow, but at a slower rate after 1973: 4.7% per year compared to an annual rate of 8.9% for electricity; and 5% per year compared to 6.6% per year for gasoline. Gasoline now represents about 19% of state energy consumption.

Energy use patterns vary among the counties. Energy consumption in the City and County of Honolulu appears to grow about 2.5% each year, and in Hawaii County, about 3.3%. The rapid economic growth of Maui has been reflected in an annual energy growth rate of about 9% in recent years. Kauai, in contrast, has shown a relatively steady increase of about 5.4% per year since 1968. Electricity prices range from about 6 cents/KWh on Oahu to 14 cents/KWh on Molokai.

Among data that have been assembled on end uses of energy, those compiled by electric companies afford the most detailed picture. In general, however, highly detailed data on energy end use have not been collected in Hawaii. Such information will be essential for evaluating specific opportunities for energy savings and creating effective energy conservation and end use efficiency programs.

Figure 3. Energy consumption by county



Projecting Hawaii's Energy Future

The projections of Hawaii's energy future were formulated from a set of analytical procedures which incorporated economic and technical data on the applicable technologies derived from analyses and expert opinion. The somewhat restrained estimates of cost and rate of commercial evolution adopted in this study may not be in accord with more optimistic expectations for energy self sufficiency and the development of specific technologies. It is notable, however, that developing indigenous energy resources appeared economically feasible with both a high and a moderate price rise and with or without aggressive energy conservation.

The analytical procedure began with the Hawaii Energy Demand Forecasting Model, which projected annual energy demand by county to the year 2005, based on what the Hawaii DPED called the "most likely" projections for population and economic growth and response in demand to the prices of fuels and electricity.

A Supply Optimization Model then analyzed how indigenous energy resources and oil could be used to meet the demand as time progressed. This procedure selected a combination of feasible technologies which minimized the price of electricity for each county, subject to technical and resource constraints. The price, in turn, was based on the capital costs, fixed charge rate, and the costs of operations, maintenance, and fuel for each technology, taking into account changes in these costs with the passage of time.

The next step was an energy supply analysis which determined — year by year to 2005 — the total costs, the direct labor requirements, and the material requirements for construction and operation of the projected electricity supply system.

The final step determined the indirect economic effects in terms of labor required and income produced in providing the goods and services needed for construction and operation of the projected electrical system for the state. These estimates were derived from an interindustry transaction table (input-output matrix) developed for the State of Hawaii.

Although the combination of technologies, their separate installed capacities, and amount of electricity each generates are chosen for least cost, each technology is subject to additional constraints on its development rate and ultimate commercial limit. Among constraints are maturation times of the technologies, limits on the natural resource, environmental impacts, and institutional and social barriers.

The numerous assumptions, both implicit and explicit, in the formulation of Hawaii's energy future are discussed in several volumes of this report. Several of the major premises are summarized here to help clarify the character of the three energy supply futures.

1. Two future world oil price patterns were employed, both starting at $30 a barrel in 1980. Although Hawaii paid less than this price in 1980, existing contracts soon expire and future costs of oil to Hawaii are then expected to be governed by the world oil price. Futures 1 and 2 assume the price of oil escalates at the rate of 3% per year above inflation, reaching a price of $64 per barrel (in 1980 $) in 2005. Future 3 assumes a price increase of 10% per year, leading to a 1980 $ price of $334 per barrel in 2005.
2. All three energy futures include the assumption that an interisland, submarine, high voltage DC transmission cable would be developed and in operation by 1995 between Hawaii and Oahu. A Contingency Future for Oahu, which does not include the cable, is discussed later.
3. The consumption of electricity rises and falls during each day. For Hawaii, three load periods were taken into account in formulating the electrical supply system: a constant 24-hour baseload; an added intermediate load lasting 15 to 17 hours; and a two- to three-hour peak occurring about 7 P.M. each day. For technical and economic reasons, most forms of generating equipment best serve either base, intermediate, or peak loads. Moreover, solar and wind powered systems are intermittent and may not match load patterns unless ample energy storage is provided, e.g. by batteries or pumped hydro storage, but the cost is then significantly increased. Those characteristics of electricity supply technologies which directly affect reliability and cost were taken into account in formulating the energy futures.
4. Improvement in end-use efficiency was introduced explicitly only for vehicles in Futures 1 and 3. Extensive end-use efficiency for electricity was added in Future 2. For automobiles, it was assumed that gasoline consumption follows present and projected federal mileage standards and remains at 27.5 mpg for

new cars after 1985. Other forms of energy conservation, both voluntary and mandatory, and the use of alcohol as fuel are implicit in the reduced demands forced by the rising price of energy.

5. The analysis assumed that electric vehicles are not likely to have a significant role in Hawaii's energy future before the turn of the century. No oil savings could be realized by replacing internal combustion vehicles with electric vehicles before a significant part of the electrical supply was generated from indigenous resources or coal, probably in the mid-1990s. Electric vehicles cannot yet meet consumer expectations for cost and performance.
6. Domestic, licensable nuclear reactors of a size appropriate for Hawaii's electrical grid (200-250 MW) are not available. Nuclear power also raises significant issues of social acceptability in Hawaii. If developed and if acceptable, such units would be unlikely to be installed and operating within the next 20 years. Consequently, they were not included in this 25-year projection.
7. Oil-fired power facilities that would be superceded by alternative technologies were assumed to be retained as reserve capacity to ensure reliability of the electrical supply system.
8. It was assumed that demand elasticities remained constant over the next 25 years. Such an assumption may not be justified during a period of rapidly increasing prices, rapid technological changes, or supply shortages. Indeed, events such as war, worldwide economic collapse or other widespread social and economic disruptions are impossible to account for in an analysis of this sort. For our purposes it was necessary to assume relatively stable social and economic conditions.
9. The analysis does not explicitly distinguish between centralized and decentralized technologies. The assumption is that while decentralized use of new energy technologies should be encouraged because it reduces overall demand, it cannot be expected to supply all of Hawaii's energy needs.
10. The future demand for aviation fuels was treated separately from other demands for energy. Jet fuel consumption was estimated from a projection of visitor arrivals, which anticipates increasing traffic until the end of the century and little or no increase thereafter. Figure 4 shows the total energy supplied by indigenous resources and imported oil, including that for aviation, in 2005 for all three futures. Table 1 summarizes the contribution of each technology to the electricity supply in 2005, and Table 2 summarizes present and future demand for petroleum products by major sector.

Table 1. Contributions of Major Sources of Electricity to Total Demand in 2005. (in millions of KWh)

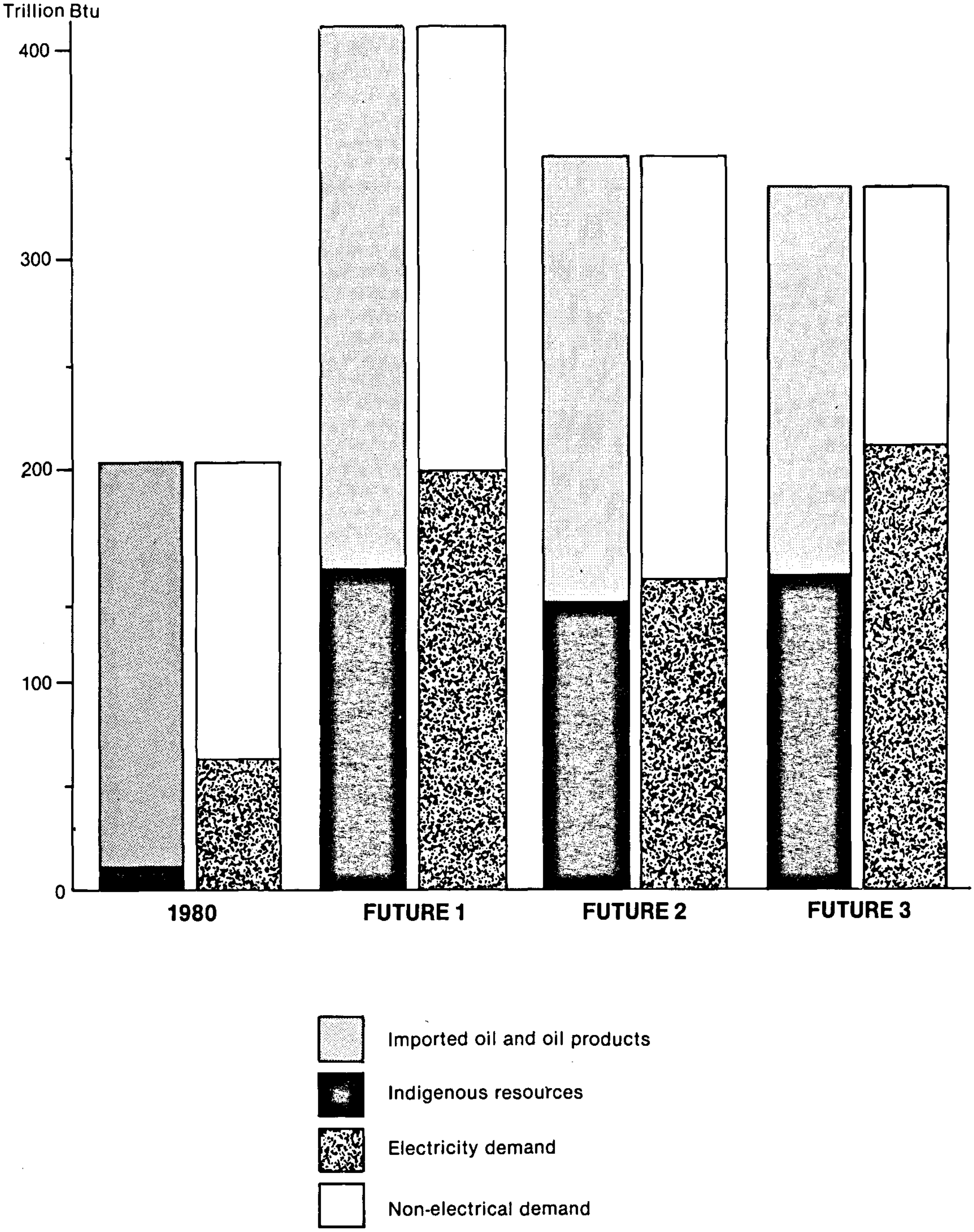
Source	Future		
	1	2	3
Oil-fired	3621	1058	923
Geothermal	5684	5339	5302
OTEC	3568	2521	2758
Wind	2314	2074	2016
Solar Thermal	1120	974	1967
Bagasse	860	860	860
Municipal Solid Waste	276	276	264
Hydro	98	98	69
Photovoltaics	0.1	0.1	204
TOTAL	17,631	13,200	14,363

Table 2. Oil Demand 1980 and 2005 (in trillions of Btu)

	1980	Future 1	Future 2	Future 3
Electricity	67	42	13	12
Gasoline	36	19	19	10
Other	34	59	59	49
Total	137	120	91	71
Aviation Fuels	69	116	116	—
Total	206	236	207	—

Note: Aviation fuel was treated separately and only a single projection, used in Futures I and II, was made. A projection was not included for Future III because it is impossible to project aviation fuel use under extremely high price escalation.

Figure 4. Sources of energy compared to demand, present and in the three futures. The electricity demand is met by indigenous resources and a small amount of oil in the futures. Non electric demand includes gasoline, residual and diesel fuel, aviation fuel, liquid petroleum gas and utility gas.



Future 1

In Future 1 the pattern of energy demand and the means to supply it take form during the next 25 years in response to a world oil price that increases 3% per year above inflation. The 3% per year was chosen for a number of reasons, but finally, it is arbitrary. It is close to the 2.8% per year projection which the DOE's Energy Information Administration made in its 1979 Annual Report to Congress. The alternatives to oil are subject to technical, economic and other constraints but must compete with oil and among themselves. Aside from federally-mandated 27.5 mpg automobile mileage standards, conservation and end-use efficiency are not explicit. They occur only to the extent induced by prices of fuels and electricity through their elasticities.

Figure 5 displays the resulting energy demand to the year 2005 for all three futures. In Future 1, total energy demand grew by 2.6% per year and nearly doubled in 25 years.

Liquid Fuels

In this future, the civilian demand for petroleum products, excluding aviation, rises slowly to a peak of 145 trillion Btu in 1990 before subsiding to 120 trillion Btu in 2005. That represents an energy oil equivalent of 21 million barrels per year, compared to 24 million barrels per year today. Aviation fuel increasingly dominates the total demand, growing from 33% of the total today to nearly 50% in 2005. In contrast, oil for electricity generation drops by one-half by 2005 from its peak of 81 trillion Btu in 1990, when indigenous resources begin to come on line. Gasoline sales drop more than 40% by 1990 and remain essentially constant thereafter at 19 trillion Btu per year (155 million gallons/yr); the increase in number of vehicles is countered by improved efficiency and driving patterns. Alcohol may then amount to 10% of the gasoline market.

The total oil demand, including aviation, increases about 15% to more than 40 million barrels per year by 2005.

Electricity

Statewide, electricity generation in Future 1 almost triples to nearly 18 million KWh in the next 25 years, but the increase varies among the counties. Domestic resources, principally geothermal and OTEC, provide nearly 80% of the electricity.

Geothermal begins to make a significant contribution (20%) to total electricity supply in the mid 1990s when an interisland and marine transmission cable is assumed to be in place. This allows the electricity generated from geothermal development on the Big Island to be allocated to the other counties, except Kauai. Wind contributes about 16% by the mid 1990s. OTEC does not make a large contribution until the late 1990s, when it provides more than a quarter of the electricity supply. Solar thermal and photovoltaics enter after 2000 when these technologies are fully developed and their costs become competitive. Some oil-fired facilities for peaking power and reserve capacity are needed through 2005 and consume about 7 million barrels of oil per year at the end of the period.

Labor and Capital

In all three futures, capital expenditures for new facilities using renewable energy resources, geothermal power and the submarine cable are assumed to be greatest between 1994 and the end of the century. According to the projections for Future 1, expenditures would average about $550 million annually. During this time, capital requirements would equal 22% of the utilities' undepreciated assets and probably 35% of depreciated assets. Some revision in current financing rules and practices may therefore be required. Beyond 2000, capital requirements stabilize.

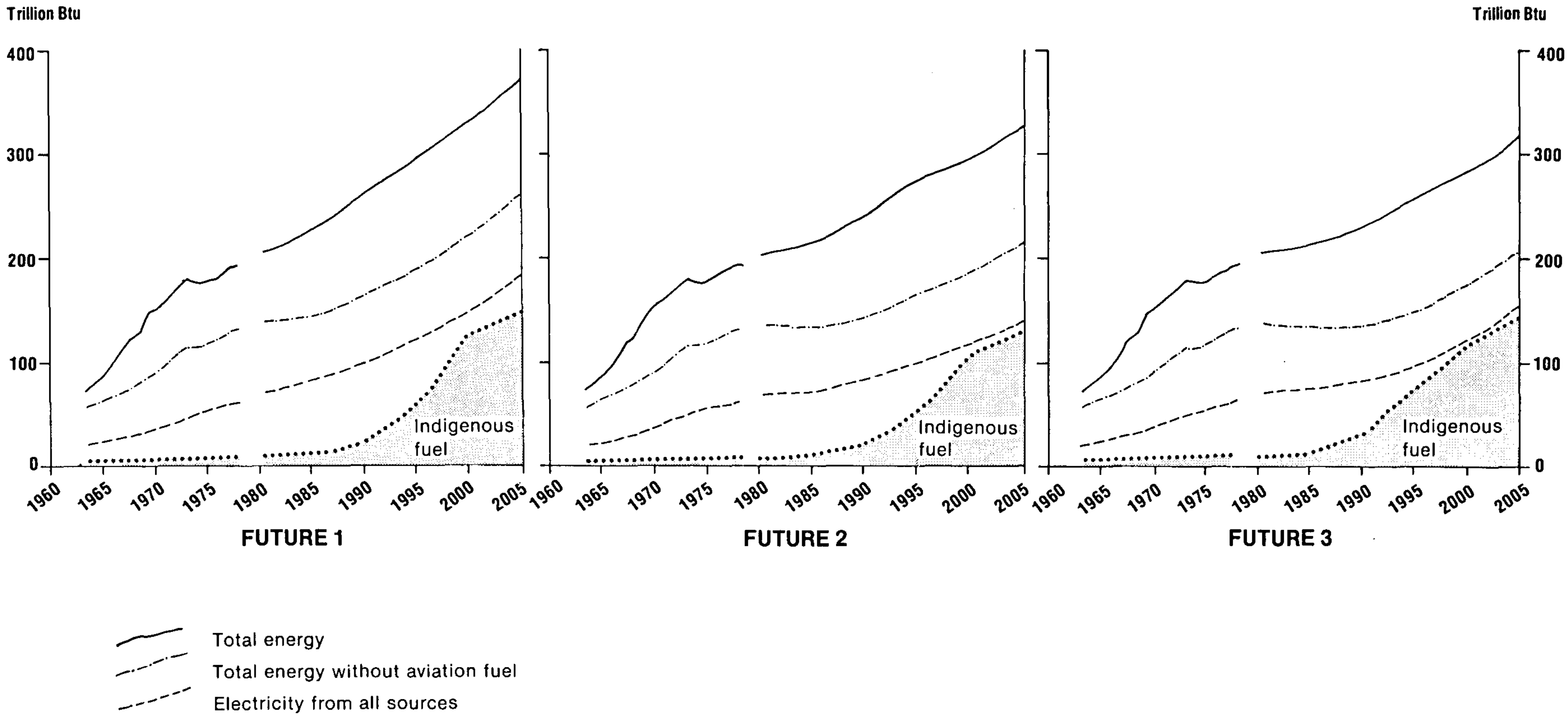
Direct labor requirements for construction would also peak in the 1994-98 period with annual employment of 950 man-years. Indirect employment associated with construction, however, would peak at nearly 10,000. Over the 25-year period, nearly 90,000 man-years would generate a total income of $2.1 billion.

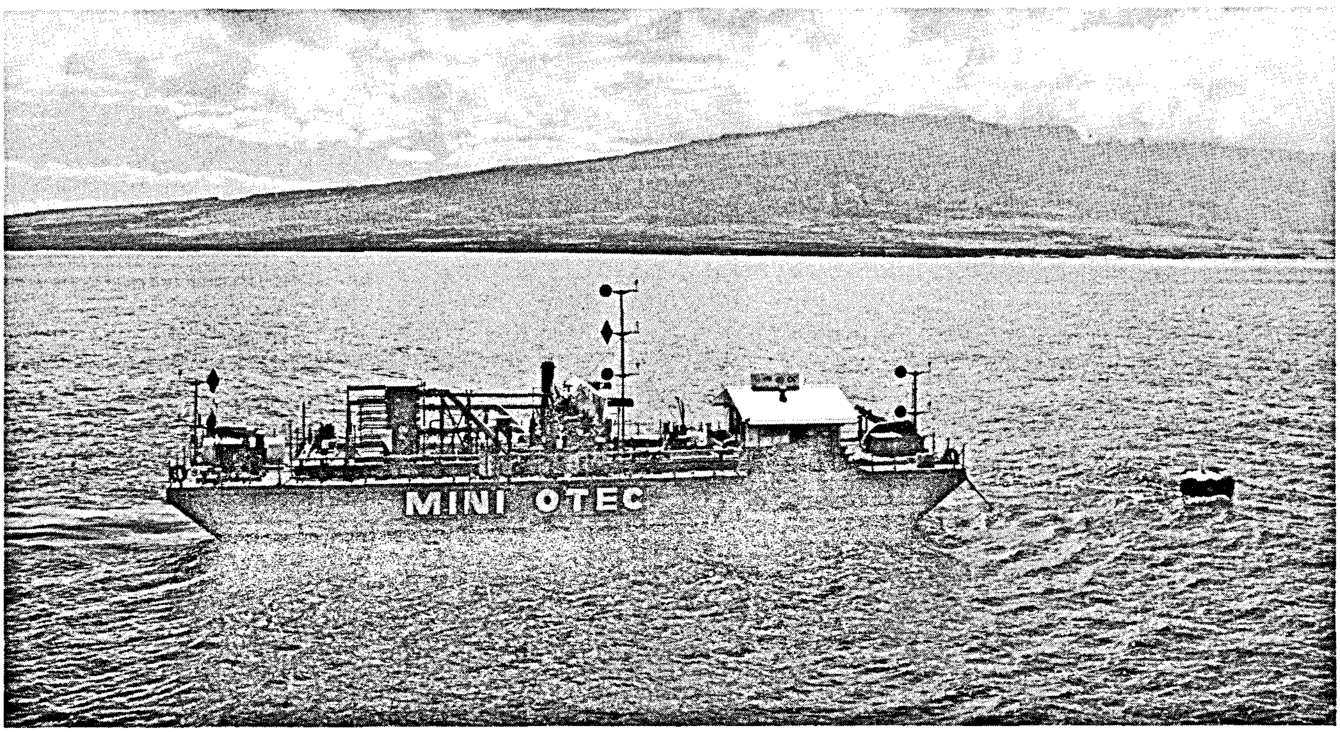
Counties

Oahu in Future 1 would continue to use its oil-fired power plants for baseload generation until 1995, but about 140 MW of gas turbine capacity would be added by 1990. The largest capacity increments would take place from 1995 through 2000 when 1,035 MW of new wind, OTEC, geothermal, and solar thermal capacity would be brought on line, requiring annual capital expenditures exceeding $400 million per year. By 2005, OTEC and geothermal would supply over one-half of total annual electricity generation of 17.6 billion KWh.

Maui County would need additional oil-fired and gas turbine capacity during the next decade. Geothermal and

Figure 5. Energy demand for the state of Hawaii, 1963–2005. Oil and oil products meet all but a fraction of the demand until the mid 1980s when indigenous resources begin to supply most of the electricity. In all three futures, indigenous resources are used for electrical generation up to the limits imposed by the constraints.





Among Hawaii's energy advances was the historic deployment and success in 1979 of the world's first at-sea, closed-cycle ocean thermal energy conversion project, called Mini-OTEC. Above, the barge in operation off Keahole Point, Island of Hawaii. Warm surface water is used to heat and expand ammonia, which in turn powers a turbine to produce electricity. Cold water from the depths condenses the ammonia to continue the cycle.

OTEC for base load, and wind and solar thermal for intermediate load would replace nearly all the oil generation after 1990. By 2005, oil for peaking power would supply less than 5% of the total 2.6 billion KWh. OTEC and geothermal would provide about 60% of total electricity requirements; wind and solar thermal, about 25%. Hydropower and bagasse would continue at their current levels. The price of electricity would rise to 100 mills/KWh.

Hawaii County would rely completely on geothermal for baseload electricity. Oil would be phased out of base and intermediate load generation and supply only a small amount of peaking power by 2000, while bagasse and other agricultural wastes would remain about the same as today. Wind and solar would be used primarily for intermediate load. A total of 154 MW of geothermal capacity, 78 MW of wind, and 17 MW of solar thermal would be constructed by 2005, when total demand would be 1.4 billion KWh at 77 mills/KWh.

Kauai's Energy Future 1 differs from that of the other counties because the interisland cable would not reach it. OTEC, along with hydroelectric and bagasse, would supply baseload power after 2000. About 38 MW of OTEC and 28 MW of wind capacity would be constructed. Since Kauai presently has excess capacity, no new power plants would be required before 1990. Total demand in 2005 is 0.6 billion KWh, at 100 mills/KWh.

Table 3 shows the projected generating capacities in 2005 for both oil and the indigenous resources in all three futures.

Table 3. Projected Electricity Generating Capacity — 2005 (in megawatts)

Resource	Future		
	1	2	3
Wind	660	592	631
OTEC	596	411	450
Geothermal	927	871	865
Solar Thermal	257	223	453
Photovoltaics			116
Municipal Solid Waste	45	45	45
Diesels and Turbines	632	401	350
Agricultural Waste	164	164	164
Hydro	17	17	17
Oil[a]	1,408	1,382	1,375
Total	4,706	4,116	4,466

[a]Existing oil generating capacity is expected to be retained as reserve and peaking capacity only.

Future 2

Future 2, like Future 1, is driven by a 3% per year escalation in world oil price over inflation, but it includes additional explicit energy savings that are not spurred by oil price alone. In addition to mileage standards, projected improvements in the efficiency of end uses of electricity, particularly for appliances, are incorporated. The impact on electricity demand, although not as fast or profound as that caused by the high oil prices in Future 3, is nevertheless substantial as shown in Figure 5 and Table 2. On the average, total energy consumption, excluding aviation, increases about 1.9% per year, or 60% by 2005.

Liquid Fuels

Aside from aviation, the demand for liquid fuels decreases rapidly in Future 2 during the 1990-2000 decade and ends the 25-year period at less than 70% (90 trillion Btu/yr) of today's demand. In contrast, the amount of oil required specifically for electricity generation drops precipitously after 1990 from 67 to 13 trillion Btu/yr in 2005 in response to energy savings and the switch to indigenous resources. If the consumption of aviation fuel is the same as that projected in Future 1, i.e., 116 trillion Btu/yr by 2005, the total oil demand rises slowly until 1995 before falling again to about the present level. Thus, jet fuel to sustain tourism is the critical factor in attempting to reduce dependence on oil, even with conservation in other sectors.

Electricity

Future 2's electricity generation approximately doubles in the next 25 years to 147 trillion Btu per year. The rate of increase is low (about 2% annually) until 1990 when less expensive, indigenous energy comes on line. By 2005, indigenous resources supply 92% of the electricity, displacing the equivalent of 23 million barrels of oil per year. In general, commercial entry of geothermal, OTEC, wind and other sources follows the pattern found in Future 1.

Labor and Capital

Trends in capital and labor requirements in this future are the same as those in Future 1 although at somewhat lower levels because of the smaller demand for electricity. During the next 10 years capital requirements total $1.1 billion.

The period from 1994 to 1998, however, would call for capital expenditures of $400 million per year. As in Future 1, this raises a potential problem of financing at the level of one-fourth the utilities' accumulated undepreciated assets. Approximately $4.7 billion would be expended on new construction over the next 25 years.

Labor requirements for construction in Future 2 are 200 to 300 man-years per year through the 1990s, and 400 after 1995. The peak occurs in 1995, when 900 man-years are required. For the entire 25 years of this future, indirect employment totals 74,000 man-years with an income of $1.7 billion.

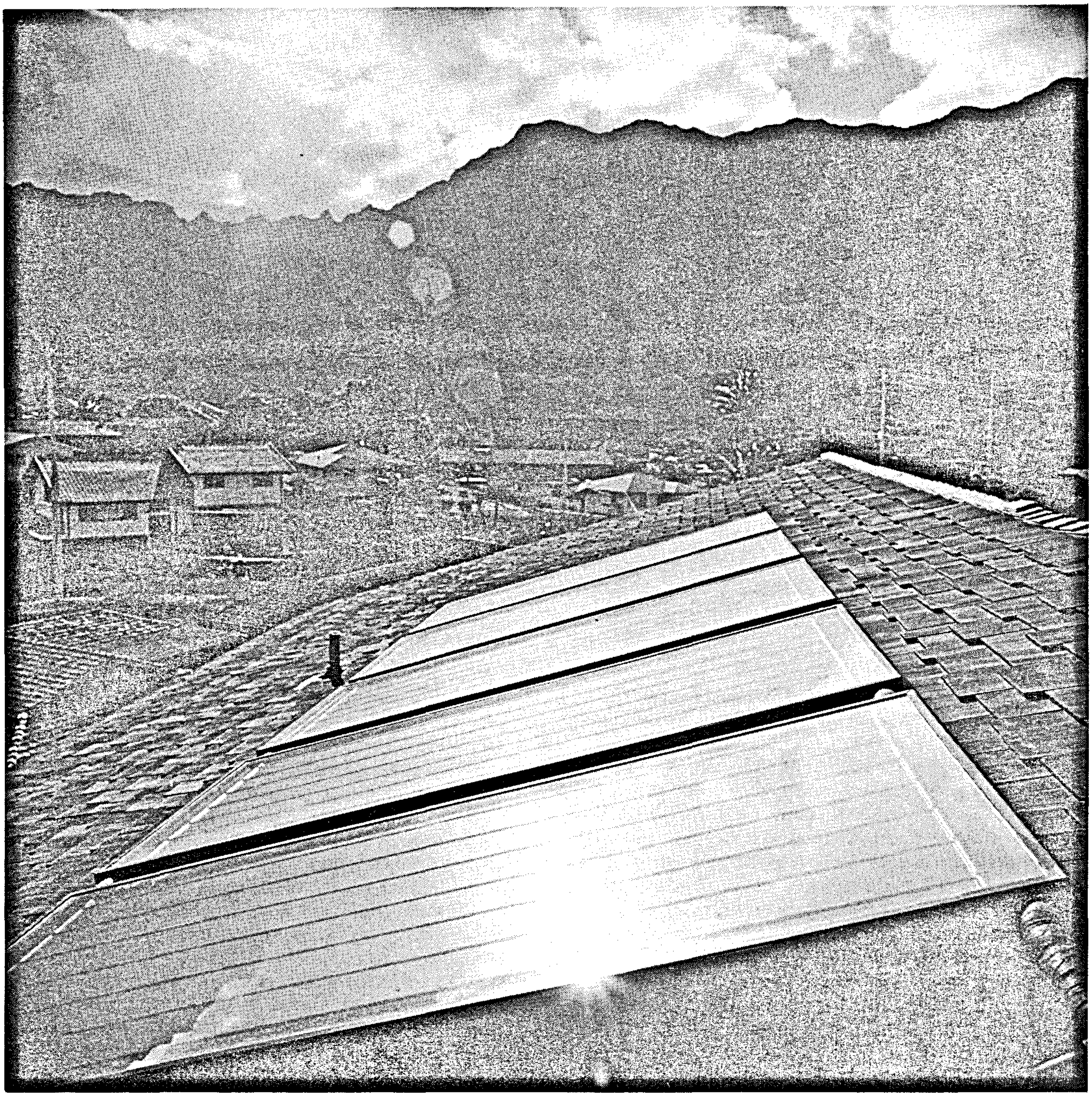
Counties

For Oahu in Future 2, oil would be the primary fuel for electricity well into the 1990s. OTEC, geothermal and wind generation become important after 1990, and by 2005 they supply baseload power, with wind used whenever available. By 2000, oil-fired generation would account for less than 10% of the total. The existing oil-fired units would remain on line, serving mainly as a back-up for wind. Solar thermal would not be a significant source of electricity until the year 2000, when it would furnish about 7% of demand. Electricity rates would then be about 20% higher than at present.

Because of the rapid growth in electricity demand on Maui, new oil-fired generating units would be needed in the 1980s. Wind and geothermal play a larger role after 1990, and OTEC after 2000. By then, oil would supply less than 10% of the electricity sold. Bagasse would continue to be used at current levels. Some gas turbines would be built to supply peak power. As on Oahu, solar thermal would begin to contribute about the year 2000.

Oil-fired generation would nearly disappear from the Big Island when geothermal power plants come on line in the late 1980s. Bagasse would continue to be used at about the present level, but there would be increased use of wind after 1995. However, some diesel and gas turbine peaking units might still be required. Solar thermal would not be significant on Hawaii because of its high cost compared to geothermal. With the bulk of energy supplied by geothermal, electricity costs would ultimately return to the present level.

Kauai will not receive geothermal power from Hawaii, nor is solar thermal expected to be competitive. Instead, the county would rely on OTEC and bagasse to supply two-thirds of its electricity in 2005. The remainder would come primarily from wind and hydro-electric. Gas turbines would continue to supply peaking power.



During 1980, Hawaii approached the 15,000-mark in the number of solar water heaters used in the Islands. Such heaters receive the free fuel of the sun and help the Islands toward its goal of greater energy self-sufficiency. Millions of barrels of imported oil can be replaced by use of solar energy.

Future 3

Energy demand and supply in this future are driven by a world oil price that rises 10% per year over inflation to reach $334 per barrel (in 1980s) in 2005. The 10% per year rate of increase serves two purposes. The first is to gauge how responsive the transition from oil to indigenous energy resources is to oil price. Second, because very high prices lead to much lower consumption, Future 3 can also be viewed as a future in which strong incentives and mandatory measures are instituted to encourage end-use conservation and efficiency and conversion to indigenous energy resources. Aside from projected automobile mileage standards, conservation was not explicitly introduced in this future, and unconventional energy technologies were subject to technical, economic, and resource constraints. The projected demands for liquid fuels and electricity for the state are shown in Figure 5 and the electricity production by technology in 2005 in Table 2.

Future 2 clearly showed that conservation could make a major difference in demand, but Future 3 demonstrates that oil price alone, if it were allowed to escalate by 10% per year for a long enough time, could depress demand growth even more. In this analysis, the 10% per year price rise slowed demand growth to less than 1.7% per year, excluding aviation fuel, leading to an increase of only 50% by 2005.

Liquid Fuels

Petroleum-based fuel demand, excluding aviation, decreases by almost 50% by 2005 to 71 trillion Btu (about 12 million barrels per year) in this high price future. By 2005, only about one-seventh as much oil would be needed for electricity generation, and for ground transportation about one-fourth as much as would be consumed today. Together, they would require about 3.8 million barrels per year. On the other hand, without indigenous resources, the non-aviation demand for oil would increase 50% to 210 trillion Btu.

A sustained 10% per year rise in oil price and the attendant increase in the cost of air travel could be expected to severely depress visitor arrivals and the demand for aviation fuel projected in futures 1 and 2. This would, in turn, affect projections of other demands for energy because of its dramatic effect on Hawaii's economy, but this analysis is unable to assess clearly how the transition to indigenous resources would be affected.

Electricity

Electricity consumption in Future 3 increases at 1.4% per year until 1990. Between 1995 and 2005 the demand increases hold to 4.7% per year in response to the lower price of electricity generated from indigenous resources, which account for 94% of the electricity supply by the year 2005. Geothermal and OTEC would then supply 60% of the total, and solar and wind about 28%.

Labor and Capital

The steeply rising oil price in this future rapidly makes new technologies competitive with oil-fired capacity. During the first decade, $1.5 billion would be expended on new construction, with expenditures representing 20 to 25% of undepreciated utility assets which could prove to be a constraint on financing new construction. A total of $5.9 billion in capital expenditures would be required for the 25-year period.

At the peak of construction in 1990, direct employment would reach 800, and indirect employment would call for 7,700 workers and generate income of $180 million. During the 25 years, indirect employment would total 100,000 man-years and generate an income of 2.3 billion.

Counties

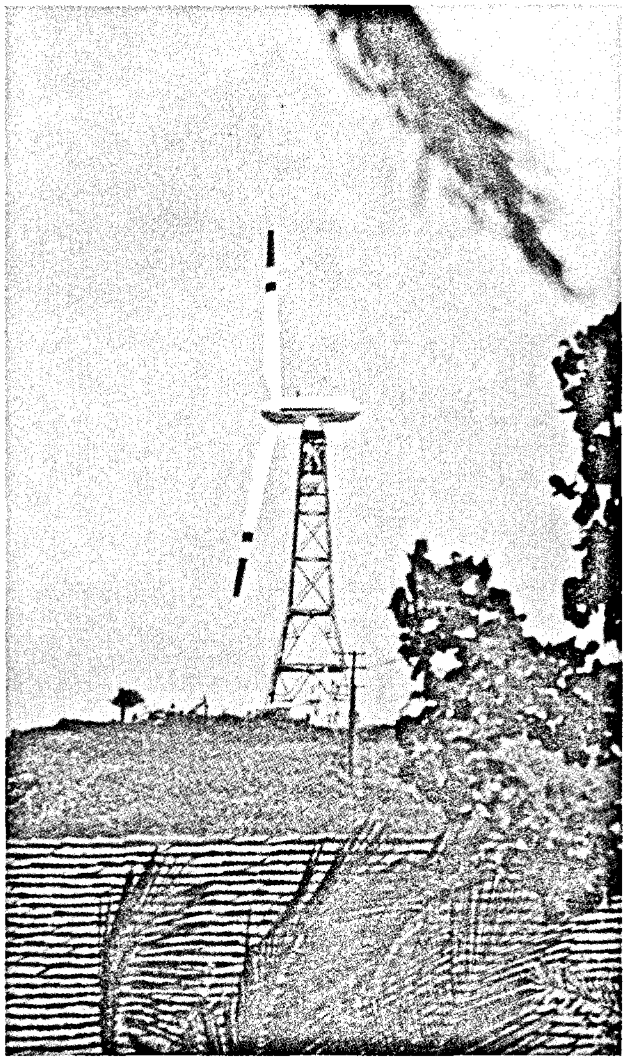
Oil would remain the primary source of electricity on Oahu through the 1980s in Future 3, but its use would decline sharply after 1990. By 2005, all the indigenous resources would play a role in electricity generation. OTEC, geothermal, solar thermal, and wind would reach the limits assumed for their generating capacities, producing 52% of the supply. Photovoltaics would attain a capacity limit of 116 MW by 2005. Although the existing oil-fired units would stay on line as a reserve capacity, they would account for only 8% of total generation.

On Maui, all the new technologies except photovoltaics would be used in 2005. Solar and geothermal would account for 26% and 19% of the total installed capacity, while wind and OTEC would account for 16% and 1%. These four technologies supply over 62% of the electricity in 2005. This percentage is much higher than for Oahu where the demand is greater and indigenous resources would reach their capacity limits.

On the Big Island, geothermal and biomass would supply all the baseload power, with solar, biomass and wind providing the bulk of the intermediate load. Wind and a small amount of oil would be used primarily for peak loads.

Kauai would rely on biomass, solar thermal, wind, hydro and OTEC for most of its power. Biomass would continue to be used, along with gas turbines and oil, but diesel peaking units currently used on the island would be phased out.

Coal: The Contingency Future for Oahu



This 200-kilowatt experimental wind turbine provides electricity for the Hawaiian Electric Company grid near Kahuku on the Island of Oahu. At least 84 megawatts of wind-generating capacity should be installed in the State of Hawaii by 1984.

The preceding analysis assumed that after 1995, a substantial fraction of Oahu's electricity would be supplied by cable from geothermal power plants on the island of Hawaii. If a submarine cable system is not successfully developed by the mid 1990s, Oahu's electrical supply system could take a different form from that projected. Kauai, Maui, and Hawaii counties would be little affected, although electricity rates on Maui would be slightly higher because of greater dependence on somewhat more costly technologies and oil. Geothermal development on the Big Island would be limited to serving domestic demands for energy.

Without the cable, Oahu would have the choice of continuing to depend on oil-fired power plants for much of its base load or switching to coal for this purpose. The first alternative would leave Oahu with an electrical system heavily dependent on oil. It would be subject to interruptions in supply and to high electricity rates until after 2005 when indigenous resources would be more fully developed.

Coal could offer an economically attractive, lower risk alternative to oil. Conventional coal handling and burning technology is well established, and ample coal is available from the U.S. and foreign sources.

If an early decision were made to rely on coal, it could be supplying baseload power by the early 1990s. In the Contingency Future, the price of coal is assumed to track the lower price pattern for oil, starting with a 1980 price of $55 per ton delivered to Oahu.

If coal instead of geothermal power were used on Oahu, the price of electricity from the whole generating system after 1990 could be expected to be slightly higher (129 mills/KWh with coal, compared to 114 mills/KWh with geothermal), and as a result, the demand for electricity would be slightly lower. The future consumption of petroleum products would be affected about the same way by both coal and geothermal power except for a transient difference around the turn of the century when the demand for oil would be significantly higher (47%) than it would be if geothermal power were available. In this future, coal imports reach 1.3 million tons per year in 2005.

While coal would be available to help Hawaii make the transition away from oil perhaps even earlier than geothermal power, its use would present difficult air and water pollution and solid waste problems. Coal-fired power plants in Hawaii would face both public disapproval and resistance from the tourist industry, which depends on the state's unique environment. Compliance with emission standards might be difficult to achieve at acceptable costs, and the disposal of ash and sludge on Oahu would be a particularly demanding problem to solve. In addition, switching to coal would require that a large shipping and handling infrastructure be built. Finally, coal, like oil, is not a renewable resource, and it must also be imported.

The Alternate Technologies

The alternate energy technologies considered in this study were chosen because they rely on resources indigenous to Hawaii and because they are expected to be ready for large-scale commercial use, primarily to generate electricity, in the next 25 years. The selection process took into account the present state of development of the technologies, projections of their technical and economic feasibility, and potential environmental, social and institutional constraints on their development. (Detailed discussions of these aspects of the technologies are in Volume II of this report.)

With the exception of biomass-fired steam generation and a small amount of hydropower, none of the technologies has had significant commercial operating experience in Hawaii, and of the others, only geothermal energy is ready for commercial deployment. Expert estimates of capital and operating costs and rates of commercial penetration therefore differ, sometimes widely. In recognition of a tendency to underestimate costs and development times, the estimates used in this study are not the most optimistic. Table 4 lists the alternate technologies that can reasonably be expected to have a role in Hawaii's electricity supply in the next 25 years. Again, all costs are expressed in 1980 dollars.

Among potential changes in the end uses of energy, only the electric vehicle and solar water heating were considered. Other end uses are amenable to improved efficiency and conservation without major shifts in technology.

Hawaii's land area is limited, and many uses compete for it. Each of the renewable energy technologies has its own land use requirements. Planning for a transition to renewables should include an intensive land use survey to identify the best sites for power plants fueled by indigenous renewable resources. Location of the resource will have to be considered in the context of present land use patterns and laws, land costs, expected trends in population growth, the presence of other energy sources, competing uses including military uses, and environmental impacts.

All of the alternate energy technologies likely to be used in Hawaii will need some government backing to carry them through to full implementation, and all will have some environmental and social impacts. Even geothermal power, which is already in commercial use elsewhere, cannot be developed to its fullest extent unless an undersea cable links the islands, and that cable will require subsidizing in the R&D stages. Construction always involves considerable site disturbance and noise; increased transportation, especially trucking; and often, the creation of new access roads. Even when the final plant is relatively inoffensive, access roads will remain and transmission lines will become a new feature of the landscape.

Baseload Technologies

Baseload generating facilities meet the major part of electricity demand and must operate continuously at high capacity and relatively low cost. Baseload technologies indigenous to Hawaii include geothermal, ocean thermal energy conversion (OTEC), and biomass-fired steam plants. The latter may be subject to seasonal variations in fuel supply.

Geothermal Energy

At least 20 potential geothermal regions have been identified in the four counties of Hawaii. Several promising fields with predicted temperatures suitable for electricity generation are located on Hawaii and possibly Maui, but only the Puna site on the Island of Hawaii has been proven with a test well. That 676°F (355°C) hydrothermal well, in the hottest known geothermal reservoir, has an estimated potential of 100 to 3,000-MW centuries and could support a generating capacity as large as 3,000 MW. The entire Kilauea East Rift Zone is believed to contain geothermal energy, and additional promising sites are located at Ka'u. Other reservoirs on Oahu are believed to have lower temperatures and may be tapped for process heat in the future. Further drilling to determine the nature and extent of geothermal resources on Oahu and Maui is needed.

Because geothermal electricity generation is already commercially developed, it is estimated that 100 MW of baseload capacity could be built at Puna by 1990 and about 1,000 MW by 2005. This assumes that a submarine transmission cable to the large electricity market on Oahu would be in operation by the mid 1990s. The capital costs of geothermal baseload power plants on Hawaii are estimated to start at \$3,000/KW and to decline to about \$1,200/KW by 2005. Because of the \$800/KW costs of the undersea cable, costs on the

Table 4. Alternate Energy Technologies

Technology	When Commercialization Expected in Hawaii[a]	Suitable for Base, Intermediate or Peak Load	Capital Cost 1980-2005 (1980 $)	Assumed Maximum Resources Potential in 2005	Major Environmental, Legal, Social and Institutional Constraints on Implementation
Geothermal	Near term	Base[b]	3,000 -1,200[c]	1,000 MW developed on Hawaii, expected to be used by Hawaii, Oahu and Maui	Toxic fumes, noise; industrial use of Hawaiian Home Lands; questions of ownership of rights to geothermal resources; industrial development of new rural areas; potential for volcanic destruction of facilities
OTEC	Mid term-to long term	Base	8,000 - 2,600	440 MW for each county	Construction stage requirements for large land area near beaches and marine facilities already in short supply, possible influx of workers; operating stage interference with underwater fuel lines and other cables and with surfing and swimming sites; water pollution from accidental discharge of working fluid; possible adverse effects from changes in thermal gradients or ocean temperatures
Wind	Near term	All three	2,500 - 700	20% of installed generating capacity for each county; 432 MW for Oahu	Visual impact of large arrays, subsonic or audible noise disturbing humans and animals; possible danger from broken or thrown blades; possible interference with flight operations and TV reception
Biomass	Near term	All three	1,500 - 1,500	164 MW for all four counties combined	Visual and noise pollution; competing land uses; potential for erosion; loss of recreational forest and open lands and other archaeological sites; toxic stillage discharge; competing markets for biomass resources
MSW	Near term	All three	1,200 - 2,200	45 MW for Oahu	Air and water pollution; increased noise and traffic from municipal solid waste trucking operations
STEC	Mid term	Intermediate	3,000 - 2,000	440 MW for each county	Considerable site disturbance; danger from misdirected high temperature radiation; glare interfering with flight operations; uncertainties concerning solar rights; land use issues
Photovoltaics	Long term	Intermediate	18,000 -2,600	116 MW for each county	Pollution and health and safety problems with manufacturing and decommissioning toxic semiconductor materials, site disturbance and land use issued for central systems arrays; uncertainties concerning solar rights
Hydroelectric	Near term	All three[b]	800 - 800	100 MW for all four counties combined; significantly expanded development is not expected, although the potential for nearly 250% expansion exists.	Danger of flash floods and downstream damage if dams fail, disturbance of impoundment site; legal questions concerning ownership of water and water use rights
Pumped storage	Near term	Peak	1,000 - 1,000	100 MW potential for all four counties combined	Danger of flash floods, environmental impacts at impoundment site, potential for salt water intrusion into fresh water supplies if salt water is used; legal questions concerning ownership of water and water use rights
Submarine High Voltage DC Transmission Cable	Mid term	Not Applicable	800 - 800	No theoretical limit; to be used to transmit power from island to island	Visual impact and possible damage to swimming and surfing sites where cables come on shore; navigational hazards during cable laying and repair; laws of international waters and navigation rights; little or no damage to deep marine environment expected

[a]Near term, present to 1985; mid term 1985-1995; long term 1995-2005 or later.

[b]Baseload power sources run 24 hours a day; intermediate load, 17 hours a day; and peak load, two to three hours. Wind, hydroelectric power, biomass, and its subset, municipal solid waste, can power baseload facilities only when supplies are uninterrupted by seasonal or daily variations.

[c]The range of capital costs indicates a decline in costs as commercialization takes place. No range is shown for technologies that have been commercialized for a number of years because cost in constant dollars is not expected to decline further.

other islands are expected to be $2,000/KW in 2005.

Environmental problems typically associated with geothermal development are physical disturbance of the site, noise, brine disposal, land subsidence, groundwater contamination by geothermal fluids, and air pollution, especially by hydrogen sulfide. Mitigating these impacts would add to capital costs according to the level of control required.

Additional, and often less manageable, problems relate to the serious social, economic and institutional impacts that could accompany large-scale geothermal development. This could be compounded by the effects of new industrial development attracted by low-cost geothermal power. Development plans should include careful ground work to mitigate the impacts on areas with geothermal resources.

Finally, on Hawaii, the most promising geothermal resources are located in an area where volcanic activity has occurred in this century and could occur again, damaging generating facilities or even making further exploitation impossible.

Undersea Cable

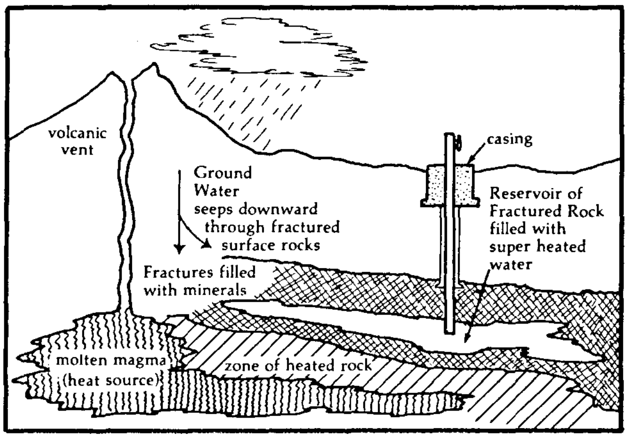
An interisland transmission cable is the keystone of any plan for a statewide electrical grid. Without such a grid, Oahu will be less able to reduce its dependence on imported oil, and all but a minor development of the Big Island's geothermal resources will be economically unjustifiable.

Submarine telegraph cables have been used since the latter half of the 19th century, but no undersea power cable has operated at depths greater than 1,800 feet or over distances of more than 80 miles. The proposed Hawaii cable will have to cross the 6,900-foot-deep (2,100 meter) Alenuihaha Channel that separates Hawaii from the other islands to reach Oahu 150 miles away.

To build the cable system, engineers must develop new cables and cable handling equipment to overcome the unprecedented structural and mechanical stresses of deep water deployment and retrieval, design adequate splices, and raise manufacturing quality control to very high levels. No foreign or domestic manufacturer now has the capacity to make the type of cable needed in the quantities required. Finally, a new generation of cable ships must be designed and built.

If a proposed demonstration cable program is successfully completed by 1984 as planned, it is estimated that the first link — Oahu to Hawaii — would be installed and on line in the mid 1990s. Maui might be added to the cable system at a later time, but Kauai is separated from the other islands by a 10,000-foot channel and is not expected to be connected to a statewide electrical grid.

Current estimates, which are necessarily highly speculative, place the total cost of a deep water, high voltage, DC cable system at approximately $1 million per mile. If the cable



In 1981, Hawaii will become the second State in the nation to generate on-line electric power from geothermal steam created by the earth's heat. The sketch above shows how the heat is tapped at the well site in the Puna District of the Island of Hawaii.

system is routed from island to island rather than from Hawaii directly to Oahu, costs will differ according to the cost of land. This study assumes an $800/KW capital cost for a total cable system.

The environmental impacts of the cable would occur mostly during the construction and deployment phase. Once in place, the cable would have little effect on the marine environment. The point at which the cable crosses the surfline and the siting of terminal facilities could cause problems in scenic and recreational areas.

OTEC

Ocean thermal energy conversion (OTEC) is an emerging technology well suited to Hawaii because the state is located in the northern reaches of the tropical oceanic belt. OTEC taps the large energy potential created by the temperature difference between sun-warmed surface water and deep, polar-fed bottom currents to generate electricity. Theoretically, the resource is virtually infinite. More practically, there are enough near-shore sites where the sea floor rapidly descends to the required depth to meet the projected demand for OTEC plant sites during the time frame of this study. OTEC plants can be sited off each island, making OTEC development independent of interisland cable development.

In the past two years, research on Mini-OTEC, Hawaii's 50 KW experimental platform, has shown that OTEC is technically feasible. Commercial scale components still need to be developed, and the economic feasibility of the system must be demonstrated. If the existing federally-funded programs are continued, OTEC should be carried through the complete research, development and demonstration cycle by the early 1990s.

The design of several major OTEC plant components is not final, and therefore all capital cost figures for commercial scale plants are speculative, However, OTEC is expensive because its extremely low (average 3%) thermodynamic efficiency necessitates very large water flows and heat exhangers, and therefore high material and operating costs. Present estimates place capital costs at about $8,000/KW of capacity for prototype plants, dropping to around $2,600/KW by 2005. Operating costs are expected to be in the neighborhood of 5 mills/KWh, compared to 2 mills/KWh for the other renewable technologies.

The major visual impact of OTEC development will take place where the cable from a plant comes onshore, although some plants may be visible from the shore. The magnitude of OTEC development planned for Hawaii is expected to have little or no negative impact on marine life.

Biomass

Biomass is the only alternate resource already being used to generate a significant amount of electricity in Hawaii. It is the only indigenous resource that could be converted to liquid fuels to supplement imported petroleum fuels. In principle, Hawaii's combined biomass resources could supply 15% of the state's total energy by 2005.

Fuels can be derived from several types of biomass resources: organic wastes of many kinds, agricultural residues, and crops grown specifically for their energy-producing potential. Because the exact nature of the biomass used determines the conversion technology, it is difficult to generalize about the costs of biomass energy technologies or the environmental problems associated with them, but combustion usually produces air pollution and solid waste problems, and fermentation can add water pollution to the list of problems to be solved.

Bagasse (a fibrous sugarcane residue), wood chips, and macadamia nut shells are now burned in conventional steam plants to generate about 12% of the electricity Hawaii consumes. Utilities purchase some 200,000 MWh of this supply for public use. In the next 20 years, mill-produced biomass generating capacity is expected to expand four-fold to reach a surplus of 100 MW. Oahu now plans 45 MW of generating capacity to be fired by municipal solid waste. Molokai Electric projects that 50 to 60% of its needs could be met in the near term by burning a combination of pineapple wastes and hay. Kauai now obtains 51% of its electricity from biomass; and more capacity is planned. Hawaii Island generates almost 45% of its electricity from biomass, and Maui, 23%.

With government subsidies, successful cultivation of 200,000 acres of Hawaii's commercial forest land could produce enough wood to generate up to 10% of the state's total electricity by 2005. It would require 60,000 to 70,000 acres of trees to fuel a 100 MW power plant, assuming a 10-year cutting cycle, which means that 6,000 to 7,000 acres would be harvested each year. There is competition: wood chips are now in great demand in Japan for paper pulp.

Biomass could also supply 10% of Hawaii's liquid fuel needs by 2005 if feedstocks were available. Barring the collapse of the international sugar market, molasses will be the most readily available feedstock for producing alcohol over the next decade or so. Cane trash, wood, and other cellulose materials could be processed into ethanol or methanol, but they are most economically used in direct combustion as boiler fuels. Becausee so many biomass resources are already valuable for many uses, it would take a drastic shift in market values or government incentives to redirect existing biomass resources entirely into an energy-producing program.

Intermittent Sources

Some of the most promising sites in the world for implementing solar technologies are found in Hawaii. However, solar technologies, with the exception of OTEC, are intermittent power sources. They wax and wane with the sunlight, and peak power does not often correspond with peak demand. Present energy storage technology is not yet adequate to allow Hawaii to meet its electricity needs with intermittent sources alone. The available pumped hydro-storage sites are not numerous, large or fortuitously sited enough to make a significant contribution to Hawaii's energy picture. Lead-acid batteries remain the only potentially suitable storage in the near future, but at a first cost of $125/KWh they are prohibitively expensive except possibly for short-term storage. Advanced batteries and other storage systems such as molten salts may become feasible by the end of the century. However, even without storage, wind is already competitive with oil, and other intermittent energy sources will become so later in the century.

Wind

Wind generators could contribute significantly to Hawaii's electricity supply in the next 25 years. Many excellent wind power sites have been identified in the state, and the technology is advanced enough to be practical and economical. A federally-funded 200 KW generator has already been installed at a Hawaiian Electric Company (HECO) site at Kahuku, Oahu, and it is connected to the grid. At least 84 MW of wind generating capacity should be installed in Hawaii by 1984.

Wind generators are modular, so installation and electricity production can be realized incrementally, and with a lead time of only two or three years, compared to eight to 12 years for conventional plants. In addition, wind generators can be installed on each island and do not require a statewide grid.

The major problem with wind power is that the source cannot be controlled or matched to load requirements. Utilities have had little experience with long-term, large-scale, grid-connected wind generation, and problems with grid operation and reliability will doubtless arise. As a result, most utility system planners hold that wind should not represent more than 20% of installed generating capacity. This study projects 432 MW of wind generation (or 20% of installed generating capacity, whichever is less) on Oahu by 2005.

Current costs for wind generators are about $2,500/KW. By 2005, costs are expected to drop to $700/KW, making wind highly competitive with other indigenous energy sources.

Wind generation appears to have minor environmental impact. Bird kills, insect kills, and climate modifications have been looked for and not found. The generators require little land, need no cooling water, and emit nothing more hazardous than low-level noise. Safety is not expected to be a problem with wind machines that are located away from population centers. Visual impacts may be negative, but again, remote siting could help solve the problem.

Solar Thermal Energy Conversion

Solar thermal energy conversion (STEC) uses mirrors, lenses, and other focusing devices to concentrate solar energy to produce heat which can then be used in a conventional power plant to produce electricity or for industrial process heat. The most likely near-term use for STEC is decentralized repowering of industrial generators, augmenting or even substituting for oil. At the moment, about a dozen STEC repowering projects for both utilities and industry are in the planning stages, especially in the southwestern US. This study places STEC's entry into commercial electricity generation near the end of the century.

It is difficult to make overall cost estimates for STEC. Efficiency of conversion is highly variable, depending upon the design of the heliostat system, receiver system and generators used. In addition, there is no commercial production of STEC components at the moment, and prototype plant costs include research and development. This study uses a $3,000/KW beginning capital cost, dropping to $2,000/KW by 2005. Some studies place the cost at a significantly lower figure.

Like the other solar technologies, STEC is intermittent. Molten salt storage, which stores heat rather than electricity, is often mentioned in connection with Rankine-cycle STEC. The main problems with this type of storage appear to be economic rather than technical.

A major limitation on STEC is the need for sufficient amounts of suitable land at affordable prices. STEC requires two square miles of land for each 100 MW of capacity. This is a land use requirement on the same order of magnitude per unit of delivered energy as eastern strip-mined coal plants. Hawaii has not yet carried out the intensive inventory of potential solar sites that will be needed before large-scale solar generating facilities are planned.

STEC produces little air or water pollution, but the plant site may be paved or sprayed with herbicides. Some proposed working fluids and heat storage fluids are toxic and could cause injury or fire in the case of accidental release. If solar radiation from the collectors were misdirected, it could also cause serious injury and fires.

Photovoltaics

Solar photovoltaic power systems use solid-state semiconductor devices to convert solar radiation into direct current electricity. They are valued for their reliability, but because of their high cost, they have been used only as remote, off-grid, low-power sources for microwave repeater stations, weather stations, seismic monitoring equipment and space craft.

Nearly all of the photovoltaic devices produced to date have employed very thin (200 to 250 micron) slices of purified, single crystal silicon. They display a conversion efficiency of 10% to 14% and last about 10 years. Further research is expected to raise conversion efficiencies to 18% and to double the lifetime of the cells.

Despite the proven reliability of silicon solar cells for small-scale applications, their high production costs and their relative inefficiency have led to research on other semiconductor materials. The technology is evolving rapidly, and while current capital costs can be set as high as $18,000/KW, it is expected that by 2005 costs will have dropped to $2,600/KW.

In the meantime, photovoltaic power systems may be used to power drip and trickle irrigation systems in the 1980s. Grid-connected photovoltaic power systems may be competitive with conventional electric generation by 1990 in isolated areas that now rely on costly diesel fuel. Molokai and Lanai, with their small, high-cost power grids, are both prime candidates for photovoltaic implementation.

If some of the newer, more toxic semiconductor materials are widely used, health hazards are likely to occur in manufacturing and when arrays are decommisioned. Dispersed deployment allows photovoltaic arrays to be built into the buildings they serve, but land requirements for central station receivers are expected to be similar to those for solar thermal power: about two square miles per 100 MW of capacity.

Hydro-Electric Power

A small amount of hydro-electric power has been developed on Hawaii, Kauai and Maui. These facilities produced just under 100 million KWh of electricity in 1979, or about 1.5% of the kilowatt-hours consumed in Hawaii that year. Many hydropower plants were originally built to provide electricity for plantations, and some have since been decommissioned as more reliable, less intermittent sources of power have become available.

Most of the potential hydropower sites which are undeveloped are found on Kauai, Hawaii and Maui, although there is some possibility for small amounts of hydropower on the other islands. If all of these sites were developed without regard to environmental considerations or competing water uses, hydropower capacity in Hawaii could reach 100 MW, or almost 5% of the total state energy demand by 2005. It is unlikely, however, that this level of hydropower development will be achieved. This study assumes the same amount of hydropower contribution to the state's energy picture in 2005 as in 1980, meaning that hydropower will continue to be important only in some localities.

Pumped Hydro-Storage

Oahu would appear to be an ideal place for pumped storage for peaking power because it has high elevation regions suitable for storage and an ocean nearby. However, if salt water were used, potential problems of salt water intrusion into the fresh water system on Oahu and the other islands would reduce the attractiveness of this resource. Despite the existence of promising sites, pumped storage is not expected to occupy a significant place in Hawaii's future electricity supply system.

Other Alternates

Two alternate technologias which have been considered for Hawaii seem unlikely to contribute substantially to the state's energy self-sufficiency in the near term. They are nuclear power and electric vehicles.

Nuclear Power

U.S. utilities tend to limit the size of their largest generating units to about 10% of the total system capacity to ensure reliabbility. Even on Oahu, which has a grid capacity of 1,800 MW, the prudent size of a nuclear-powered unit would be under 200 MW, and not more than 250 MW by 1990.

The only reactors now available are in the 1,000 MW range, and small reactors will probably not be available for purchase in the United States for at least 15 years or longer. Several European vendors have plans to develop small reactors, but their production will depend largely on the development of a market for them in the third world, and the growth of this market is uncertain.

Vendor estimates of development times for small reactors range from nine to 12 years, but this must be considered a lower bound. When and if a small reactor becomes available, manufacture and plant construction may add another five to 10 years for early models.

Cost estimates for small reactors are highly uncertain. Rolls Royce, Ltd. has estimated a cost of $2,700/KW for complete installation of its proposed 200 MW, barge-mounted, pressurized water reactor. Taking into account regulatory delays, public protest, environmental constraints, and the tendency of vendors to underestimate costs, such estimates must be viewed with skepticism.

It should be particularly noted that a climate of acceptance for nuclear energy is not found in Hawaii. At the least, surmounting political, regulatory and social barriers could consume much of the next three decades, especially if, as seems likely, the plants are designed and built abroad and are therefore not tailored to U.S. regulations.

Electric Vehicles

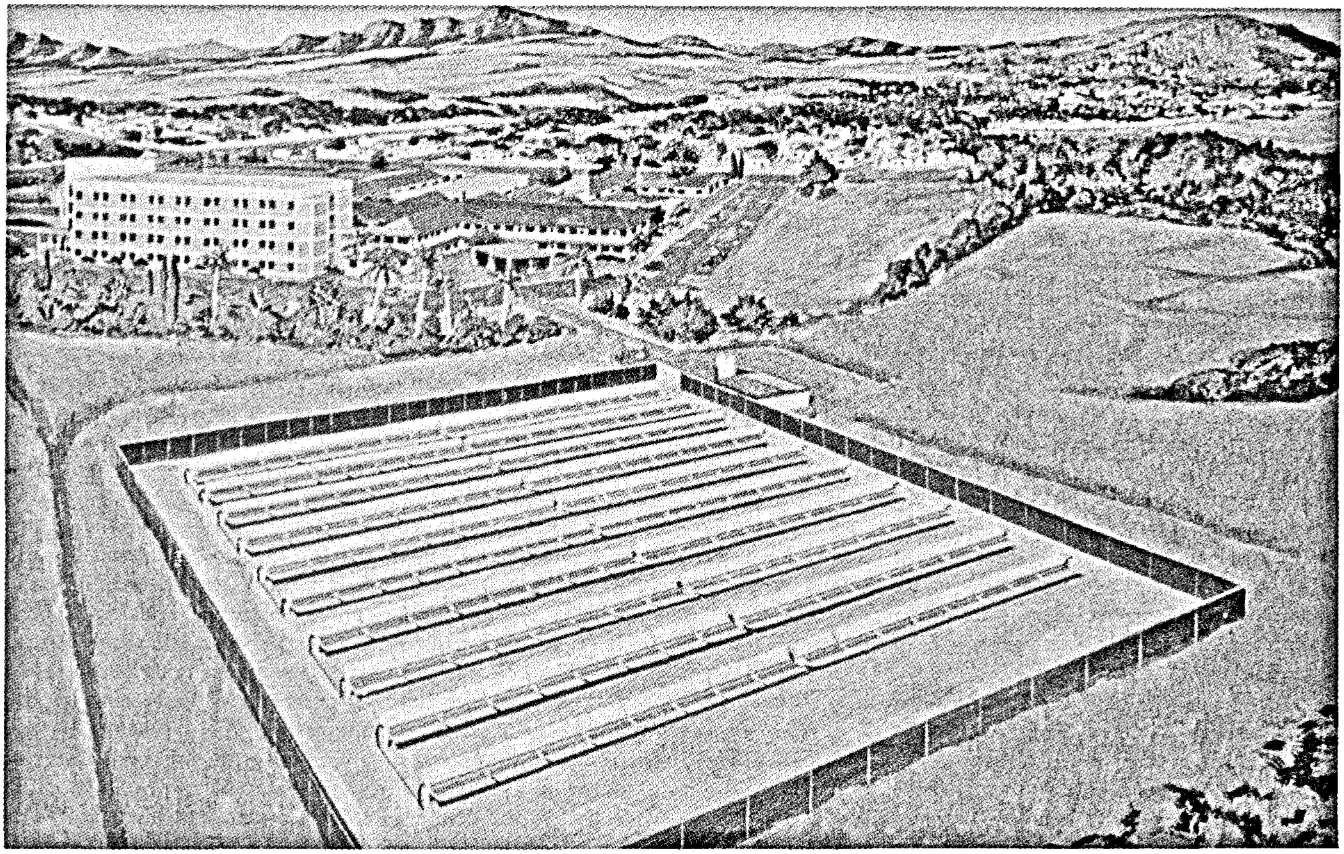
Electric vehicles have been considered as a means of reducing the large proportion of Hawaii's energy that is now used for ground transportation. Privately-owned electric vehicles, however, are not likely to displace the internal combustion engine car in Hawaii within the next 25 years.

In the near term, while almost 90% of Hawaii's electricity is still generated by oil-fired power plants, electric vehicles would use petroleum indirectly and less efficiently than gasoline-powered cars. Once indigenous energy sources begin to supply most of Hawaii's electricity in the mid-1990s, electric vehicles could, in principle, reduce oil demand, although their effect on subsequent demand for oil-fired peaking power would have to be examined and possibly regulated.

A second level of problems results from the inadequacies of present batteries. Today's lead-acid battery has 1/1000 the specific energy (Watt-hours/kilogram) of gasoline. State-of-the-art electric vehicles have a range of about 50 miles, and they do not perform well on the hilly terrain that Hawaii has in abundance. They are small but heavy and cost more than conventional cars. An electric vehicle which could meet the expectations of modern drivers would have to be the size of a Greyhound bus, 80% of which was filled by batteries.

It is difficult to say when electric vehicles will be able to meet consumer expectations for performance and cost. Optimistic estimates place a breakthrough in the 1990s, just about the time Hawaii could have enough surplus electricity to accommodate EV's. Current research is directed toward a small, energy-sufficient, lightweight battery with power available for performance and enough energy storage for a larger range. Hawaii alone, with its 600,000 vehicles, does not present large enough market to spur manufacturers to special R&D efforts.

Once battery technology is advanced enough to make electric vehicles feasible, it would still take 10 years or more for most of the Hawaii passenger vehicle fleet to be replaced, and over five years before enough EV's would be in use to affect oil consumption. In addition, all facilities for repair and maintenance, as well as for recharging, will have to be developed. It is anticipated that not more than one-quarter to one-half the vehicle fleet will consist of electric vehicles by 2005, and their impact on oil demand will be minor.



This Acurex Solar Corporation sketch shows the design of the Wilcox Hospital photovoltaic energy system in Lihue, Kauai. When completed, it will be one of the first concentrating photovoltaic systems in the world and the largest solar energy system in the Islands. It will provide both electricity and hot water.

Conservation

The econometric model in Volume III of this report shows that consumers are far more responsive to price increases than to any other conservation pressure. The potential for conserving energy in Hawaii must be assessed in terms of the state's unique energy use pattern. Unlike the rest of the nation, Hawaii uses virtually no energy for space heating, and the state has very little energy-intensive industry. While jet fuel accounts for 2.5% of total U.S. energy use, it represents over 30% of the energy used in Hawaii.

Hawaii's major conservation savings could be realized in the realms of electricity consumption (31% of total energy use now) and civilian ground transportation (20%). The combined effects of technical innovation in the form of improved energy efficiencies, increased energy prices, and consumers' efforts will change not only the amounts of energy Hawaii residents expend, but also the way in which they use it. Precise estimates of these energy savings require data not yet available, but econometric modeling based on various sets of assumptions makes it possible at least to forecast basic trends in the reduction of energy consumption.

Residential energy use in Hawaii is characterized by an almost complete reliance upon electricity (45% of the state's electricity consumption). Heating water is the major residential energy use (40%), followed by refrigeration (20%) and cooking (10%). The introduction of solar water heating, along with energy-efficient electric heat pumps, is expected to have a dramatic effect on residential energy use by the year 2005, although the effect on the state's total oil imports would be a reduction of only about 1.5%. Other savings will be realized over time as more efficient appliances, including refrigerators, replace existing ones.

Commercial buildings, hotels, and multi-story apartment buildings are almost the only buildings that require space cooling in Hawaii. They use one-third of the state's electricity. It is estimated that electricity use in the service sector could decline by 20% to 40%, depending upon the size of utility rate increases, over the 25-year study period. Recent construction trends in Hawaii, however, have been toward multi-story buildings for both residential and other uses. As long as limited available land and rising population forces such a trend, design geared to minimize heating by the sun and to take advantage of natural ventilation by the trade winds could reduce the energy intensiveness of these buildings.

Finally, rising gasoline prices, coupled with federally mandated mileage standards could reduce present gasoline use by one-half to three-quarters by 2005. The development of electric-powered mass transit for Honolulu and its suburbs could further reduce transportation dependence on petroleum fuels, once most of the state's electricity is generated by alternate energy sources.

Legislative and Policy Framework

Throughout this study, it has been recognized that although the lead role in alternate energy development and commercialization will usually be assumed by private industry, the actions of the federal, state and county governments will have considerable influence in shaping the energy future of the 50th State.

Each of the alternate technologies will have to be developed within the framework of existing land use and environmental protection laws, zoning and building-code restrictions, special-use district requirements, and in some cases, even the legal determination of ownership rights and international laws governing the open ocean. Also, most new technologies will need government funding in some form during the research and development and prototype demonstration stages.

During the next 25 years, planners and decision makers in Hawaii will be working within the framework of the *Hawaii State Plan* which was enacted into law by the State Legislature and Governor George R. Ariyoshi in 1978. *The Hawaii State Plan* sets forth the state's overall goals and policies to serve as guidelines for the orderly development of Hawaii's resources to best serve the economy, the physical environment, and the social well-being of her people.

In the *Hawaii State Plan,* two basic goals for energy planning are:

- To provide dependable, efficient and economical statewide energy systems capable of supporting the energy needs of the people
- To achieve increased energy self-sufficiency

Following the adoption of the *Hawaii State Plan,* a State Energy Plan was prepared as one of a dozen functional plans mandated in specific subject areas to serve as vital links between the broad policy guidelines of the *Hawaii State Plan* and specific programs and activities of state and county agencies. The State Energy Plan, which has been extensively reviewed in public information meetings, was to be submitted to the State Legislature for approval early in 1981.

The Energy Plan gives details of specific objectives, policies and implementing actions intended to achieve state energy goals. They include:

- Improving the state's administrative capability to manage the energy program by establishing a Division of Energy within the Department of Planning and Economic Development
- Establishing county Energy Self-Sufficiency Offices with coordinating mechanisms to integrate county and statewide efforts
- Improving statewide energy information management capability by establishing an ongoing energy data management system within the Department of Planning and Economic Development and offering both state and county energy planners easy access to the system.
- Removal of legal, institutional, economic, and financial barriers which might slow the commercialization of appropriate alternate energy technologies.
- Support for research, development, and demonstration activities to expedite the attainment of local commercialization of alternate energy technologies.
- Development and support for energy conservation, education and information programs and incentives to increase the use of passive solar design, energy-conserving technology, and energy-efficient applications.
- Direction of future urban growth into easily serviceable areas for maximum efficiency in the use of energy.
- Management of present conventional sources of energy to provide development through contingency planning options, strategic petroleum reserves, and proposals for allocation of fuels in case of disruptions in world or local supplies.

The Energy Plan also provides a summary of planned and ongoing energy activities delineating lead and assisting organizations, time and budget estimates, and sources of funding. Among these energy programs are the Hawaii Integrated Energy Assessment; plans for a Division of Energy within DPED; and continued support for the Natural Energy Laboratory of Hawaii, the Hawaii Natural Energy Institute, the OTEC pilot plant development program, wind turbine demonstration projects on several islands, solar thermal power plant demonstrations, hydroelectric pumped storage facilities, and geothermal development. The state will continue its policies of providing tax incentives to encourage the use of energy-saving devices and fuels and coordinating the planning functions of county and statewide energy self-sufficiency programs.

The state will support better data systems for reporting energy supply and demand, the use of energy-efficient designs for buildings, and the streamlining of permit procedures and regulations involved in the development of energy resources.

On the county level, energy policies have been expressed in General Plans and energy self-sufficiency plans developed by the four counties. These follow in general the objectives and policies of the *Hawaii State Plan* and the State Energy Plan in terms of developing alternate resources, conservation, and public information programs. Implicit in the county plans is the concern that policies affecting the development of alternate energy resources be consistent with expressed county positions regarding population growth levels, economic development and desired land use patterns.

Achieving all of Hawaii's energy goals will require that the plans and policies of all three levels of government be in harmony, technically sound, and practical enough to enlist the indispensable support of the people of the 50th State.

The HIEA provides a tool for energy planning. It gives all levels of government the capability to assess alternate energy technology development and conservation methods and to set priorities. This seven-volume report and the supply and demand models developed in the HIEA will allow continuous monitoring of the effects of changing energy prices and supplies, technology advances, and energy-demand patterns on state energy goals. This, in the changing world of today and the future, is the purpose of the Hawaii Integrated Energy Assessment.

The Hawaii State Plan

STATE ENERGY PLAN
STATE TRANSPORTATION PLAN
STATE WATER RESOURCES DEVELOPMENT PLAN
STATE HISTORIC PRESERVATION PLAN
STATE RECREATION PLAN
STATE HEALTH PLAN
STATE CONSERVATION LANDS PLAN
STATE EDUCATION PLAN
STATE HOUSING PLAN
STATE HIGHER EDUCATION PLAN
STATE AGRICULTURE PLAN
STATE TOURISM PLAN

STATE ENERGY PLAN

DEPARTMENT OF PLANNING
AND ECONOMIC DEVELOPMENT

The State of Hawaii has developed a long-range comprehensive Hawaii State Plan *– the first such plan enacted into law by any State – which calls for 12 State Functional Plans to help implement State goals, objectives, policies, and priorities. The State Energy Plan is one of the 12.*

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